

AVALANCHE HAZARD ASSESSMENT

FOR THE

RICO-ARGENTINE MINE

PROJECT SITE

PREPARED FOR:

AMEC ENVIRONMENT AND INFRASTRUCTURE INC.
PROJECT NUMBER: 52964AV
DECEMBER 3, 2013

1.0 INTRODUCTION

This report presents our snow avalanche hazard assessment for the Rico-Argentine Mine in Rico, Colorado. Our study was requested by AMEC Environment & Infrastructure, Inc. (AMEC) and was performed in accordance with the scope of services outlined in our January 9, 2013 proposal.

This avalanche hazard study presents an evaluation and detailed discussion of the site exposure of the Rico-Argentine Mine area to avalanche hazard. Our avalanche hazard analysis is based on our surface observations, a review of available literature, avalanche mapping for the area, avalanche records from the area, interviews with site personnel and local residents dendrochronology, avalanche dynamics modeling and on our experience in the area. This study includes expected design level pressures from avalanche debris, avalanche runout distances and return periods.

This study does not include design level geotechnical engineering consultation.

1.1 *Geologic Hazard Definition and Discussion*

There are three (3) statutes that were adopted by the Colorado Legislature that are pertinent to geologic hazards and land use.

1. “The Land Use Act” of 1970 established the basis for which later bills could be enforced. The Land Use Act mandated that decisions and authority to develop and enforce land use planning regulations should be conducted at local government levels.
2. Senate Bill 35 (1972) required that local county governments either adopt land use planning regulations for subdivisions or follow a model set of regulations developed by the State of Colorado.
3. In 1974, the Colorado House of Representatives amended the Land Use Act by adopting House Bill 1041. House Bill 1041 provided legal definition of natural and geologic hazards. A natural hazard is considered any hazard from geologic conditions, wildfire, or flooding. A geologic hazard is defined as “a geologic phenomenon which is so adverse to past, current, or foreseeable construction or land use as to constitute a significant hazards to public health and safety or to property”. The geologic hazards identified and defined in House Bill 1041 include; avalanche, landslide, rockfall, mudflow and debris fans, unstable or potentially unstable slopes, seismic effects, radioactivity and ground subsidence.

These statutes formed the basis for the design and implementation of this avalanche hazard assessment.

2.0 PROJECT BACKGROUND, SCOPE OF DEVELOPMENT AND SCOPE OF STUDY

The site is divided into two areas. The St. Louis Ponds area is located east of Colorado State Highway 145 (Highway 145) north of Rico and is accessed by St. Lewis [sic] Road (Figure 1). The Argentine Mill area is located approximately one mile east of Rico along County Road N (Figure 1).

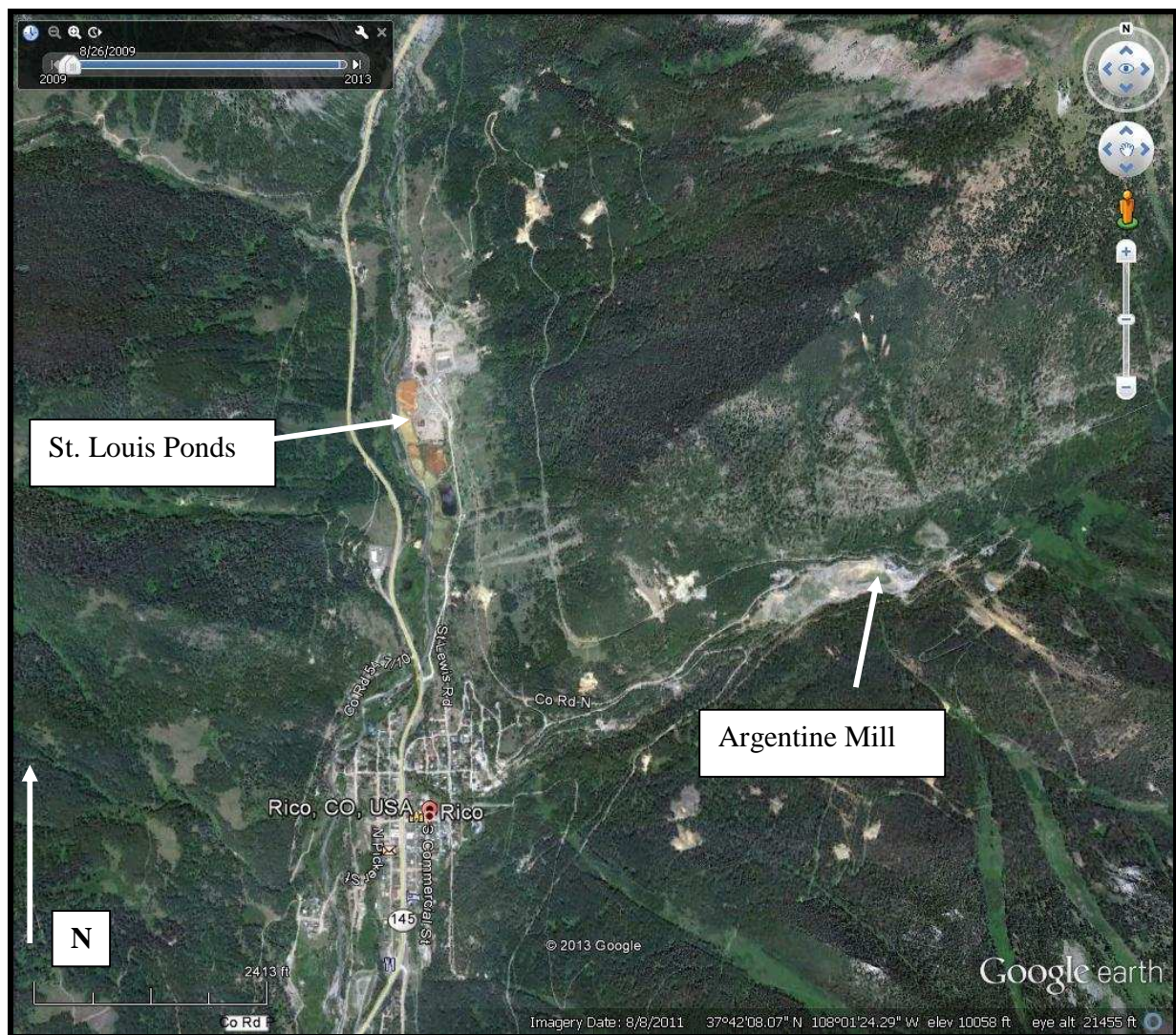


Figure 1 Location map of the Rico-Arentine Mine site.

2.1 Current Scope of Development

We understand that the proposed project will consist of evaluating the avalanche hazard on the avalanche paths in the vicinity of the Rico-Argentine Mine in Rico, Colorado and delineating the avalanche paths near the subject property.

Design-level avalanche mitigation is beyond the scope of this study. Trautner Geotech is available to design recommendations for avalanche mitigation for the avalanche paths above any proposed structures if desired. If any proposed structures will be placed within an avalanche path, avalanche mitigation should be included in the design of the proposed structure and a structural engineer should be consulted to develop a structure concept capable of withstanding the avalanche pressures and criteria outlined within this report.

2.2 Scope of This Avalanche Hazard Study

We performed a field reconnaissance of the site on June 6, 2013. The site observations include detailed observations of portions of the site to evaluate the existence and potential significance of avalanche hazards that may influence the site property. The general scope of our study included the following:

- Field observations including a description of the site topography.
- Avalanche accumulation zone characteristics, avalanche path morphology and runout zone considerations.
- We observed the site for evidence of avalanche hazards outlined in Colorado House Bill 1041.
- Identification of avalanche hazards that may influence the site.
- Tree coring to determine dendrochronology of past avalanche events and age of trees in and adjacent to the avalanche paths.
- Avalanche dynamics modeling to determine the potential runout length and impact pressures of design-level avalanches.
- Interview personnel familiar with the avalanche history of the avalanche paths.
- We prepared an avalanche hazard map which is included as Plates 1 and 2 of this report.
- We are available to provide continued consultation through the review and approval process of this project.

3.0 GENERAL AVALANCHE DISCUSSION

3.1 *General Avalanche Hazard Discussion*

Avalanche paths generally consist of three parts:

- the starting zone, where avalanches initiate,
- the track, where avalanches reach maximum velocity, and,
- the runout zone where avalanches decelerate and deposit snow and debris.

Avalanche paths can be either unconfined or channelized or have a combination of both. In Colorado, many avalanches are confined by gullies and forested areas. The destructive force of avalanches occurs as a result of two processes; the force from the powder blast which is at the leading edge of a moving avalanche, and the force from the dense flowing debris which makes up the bulk of entrained snow. The dense debris has the largest impact pressures and typically follows behind the powder blast by a few seconds. The magnitude of the avalanche impact pressure depends on the velocity of the flow and density of the snow as well as the angle of the impacted structure to the flow. The maximum impact pressure occurs on a structure with a wall perpendicular to the direction of flow. As this angle is decreased, the force per unit area or pressure decreases, so that the calculated design pressure for a structure can vary from the predicted impact pressure.

Avalanches have return periods similar to floods in that their frequency is based on the probability of avalanche occurrence. Some avalanche paths have avalanche events that occur numerous times during each winter season. Other avalanche paths only have avalanche events occurring every one to three hundred years. For example, a return period of 100 years has a probability of occurrence of 0.01 in any given year. Unlike floods, the return period of an avalanche is dependent on extreme weather events and the structure of the snowpack when the extreme weather event occurs. Similar to floods, the probability of an avalanche occurring is not dependent on the time since the last event.

Avalanche hazard zoning is usually based on the design avalanche. The “design avalanche” has a destructive potential that depends on the return period and the encounter probability. The only reliable method for accurate identification of the return period and encounter probability is a long observation period that is at least twice as long as the design period (Mears, 1992). For most zoning situations the design avalanche is based on an avalanche with a 100 year return period.

Avalanche paths near residential areas in Colorado are generally delineated into two zones; the Red or High Hazard Zone and the Blue or Moderate Hazard Zone. The Red Zone is generally defined as an area affected by an avalanche with a return period of less than 30 years or by an avalanche with a dynamic impact pressure of greater than 30 kPa (or 626 lb/ft²). The Blue Zone is generally defined as an area affected by an avalanche with a return period of 30 to 100 years and also by an avalanche with a dynamic impact pressure of less than 30 kPa (or 626 lb/ft²).

Residential and commercial structures are generally permitted in Blue Zones when some type of mitigation is incorporated into the design of the building. Generally no building is permitted in Red or High Hazard Zones. Avalanche hazard zoning is not consistent within the state of Colorado and is usually defined by the county government. Some municipalities have adopted specific avalanche hazard zoning rules.

3.2 Regional Avalanche Hazard Discussion

The site is located in the San Juan Mountains of southwestern Colorado. Avalanches typically occur in the San Juan Mountains from November through May, though extraordinary snowfall events can cause avalanches to occur earlier or later in the winter season. Avalanches in the San Juan Mountains typically stay within well-defined avalanche paths, but can over-run historic avalanche paths during periods of unusually heavy snow fall. Heavily timbered slopes are not necessarily safe from avalanches if avalanches can initiate on slopes above the timbered slopes.

Average annual snowfall for the area near the site is approximately 170 inches per year (Western Regional Climate Center). The average settled snowpack depth in the vicinity of the site is approximately 3 to 6 feet (Western Regional Climate Center), although this depth can vary considerably.

During winter 2012-2013, periodic avalanche observations were performed, and a snow study plot was established near the St. Louis Ponds area south of the site access gate (Plate 1). The snow study plot consisted of a master snow stake and a snow storm board and allowed field personnel to quantify site-specific snow accumulation, settling, and water equivalent.

The Town of Rico Land Use code, number 808.1 A, states:

A.

No dwelling units or residential structures shall be allowed in areas of High Avalanche Hazard (defined as areas where avalanches occur at a frequency of more than once per 100 years or where avalanches are capable of creating impact pressures greater than 615 pounds per square foot once every 100 years).

B. All proposed structures, improvements and other development activities must receive certification from an engineer licensed in the State of Colorado stating that the proposed development is designed to withstand the potential avalanche force; and

C. no vegetation removal which results in creating, increasing, or expanding the avalanche hazard shall be allowed in or near designated avalanche hazard areas or potential avalanche hazard areas.

4.0 AVALANCHE HAZARD DISCUSSION

The avalanche paths defined in this study (Plates 1 and 2) were identified based on historic avalanche occurrences, field observations, potential impact pressures and snow flow heights modeled with the AVAL-1D avalanche dynamics model, and dendrochronology. The following sections provide a brief discussion of the observed conditions followed by a discussion regarding potential mitigation concepts for the observed avalanche hazard.

4.1 Site Avalanche Path Characteristics

The avalanche paths in the vicinity of the St. Louis Ponds area are shown on Plate 1. The avalanche paths in the vicinity of the Argentine Mill and County Road N are shown on Plate 2. The path boundaries were delineated based on field reconnaissance, dendrochronology of select trees in the vicinity of the avalanche paths, and an examination of aerial photographs. Known avalanche paths and their calculated run-out zones (described below) are outlined in black; potential avalanche paths are represented by lines with arrows. A known avalanche path is one that was either observed to have avalanche activity during winter 2012-2013 field visits or had signs of past avalanche activity due to vegetative or dendro-chronological indicators.

Avalanche starting zones above the St. Louis Ponds area start at elevations of approximately 9,800 to 9,900 feet above mean sea level (amsl) and have the potential to run into St. Lewis Road and the ponds west of the road. In the steep treed areas above the St. Louis Ponds area, there are a few small potential avalanche paths (indicated by black arrows on Plate 1). These are low probability avalanche paths that could affect access to the St. Louis Ponds area by depositing small amounts of avalanche debris on the access road. The amount of anticipated avalanche debris could reach the access road and potentially bury personnel. Note that not all small potential avalanche paths are marked on Plate 1; unanticipated winter conditions could result in additional avalanches on previously unidentified paths.

4.2 Local Avalanche History

There is one documented historical avalanche that occurred within Rico. The Spear Slide (also known as the New Year's Slide) avalanche path, located on Dolores Mountain, is approximately one mile south of the St. Louis Ponds area on the east side of Highway 145. The Spear Slide avalanche path has been observed since the 1880s. On February 8, 1932, the Spear Slide flowed across where Highway 145 is currently located and ran to the end of the "Y" spur of the railroad on the west side of the highway. The Spear residence, located on the east side of what is now Highway 145, was destroyed in the avalanche. There were no other official records that indicated that the Spear Slide ran as far as Highway 145 again. An interview with longtime Rico resident Genevieve Yellowman revealed that the Spear Slide reached the eastern edge of Highway 145 sometime in 1972, but an exact date is unconfirmed.

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The local history of avalanche paths at the site are not documented, but Mr. Chris Sanchez of Anderson Engineering Company, Incorporated, who has worked in the site vicinity since 2005, was interviewed on the subject. Mr. Sanchez observed an avalanche in Path 3 (Plate 1) during the winter of 2009-2010 (date and time unknown) that ran over St. Lewis Road and deposited approximately five (5) feet of avalanche debris on the road. No other avalanches were observed by Mr. Sanchez during the time period of 2005-2012, but he mentioned that he did not specifically look for avalanche debris.

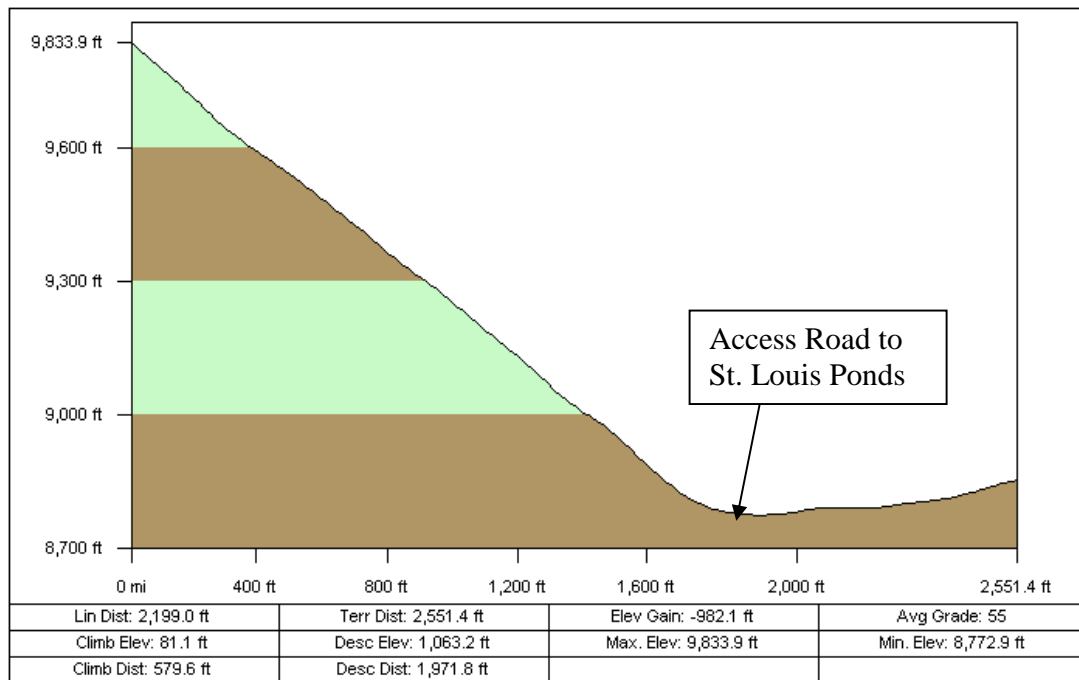
Path 3 did have an avalanche occurrence on January 30, 2013, that deposited avalanche debris within about 20 feet of St. Lewis Road. The storm that produced this avalanche had 2.55 inches of snow water equivalent, as measured at the study plot located along St. Lewis Road (Plate 1).

4.3 Avalanche Dynamics Modeling

AVAL-1D is a one-dimensional avalanche dynamics program that predicts runout distances, flow velocities, and impact pressures of both flowing and powder snow avalanches. Profiles of the avalanche paths were created using a USGS 1:24,000 scale topographic map (USGS 1:24,000 Topographic Map, Rico, CO 37108F1), a topographic map provided by Atlantic Richfield, and GPS measurements taken during site visits. A profile of Path 3 is shown in Figure 2. Parameters for the avalanche simulation were based on topographical and vegetative indicators within the avalanche path. Snow depth and density assumptions were based on NRCS SNOTEL data from the Lizard Head Pass and Scotch Creek SNOTEL sites and the Western Regional Climate Center. The average snow depths for avalanche paths were interpolated between the two SNOTEL sites.



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Figure 2. Profile of Path 3 “Sanchez” avalanche path. Note that the scale is vertically exaggerated.

Numerous calculations were performed using AVAL-1D on various avalanche paths within the study area. Not all calculations are shown in this report but are available if desired. Example calculations are shown below for the amount of avalanche debris that can be expected from these paths and the potential impact pressures from the moving debris. Results of the calculations of AVAL-1D are used in conjunction with other factors such as avalanche return periods based on dendro-chronology and site-specific topography for designating the avalanche paths shown on Plates 1 and 2.

An average slab depth of 1.5 meters was used in the calculations for a design avalanche for all avalanche paths on the site. This is based on our experience in the area and a standard for design level slab depths in the area as well as an interpolation between SNOTEL sites in the area. A depth on the ground of 1.25 meters (m) was used in the run-out calculations for the height of potential avalanche debris at the St Louis Ponds area based on typical design level avalanche slab depths for the area. The input parameters and modeling results for each slide path used in the AVAL-1D calculations are available upon request.

4.4 Path 3 Modeling Results

The calculated potential impact pressure at St. Lewis Road from the design avalanche for the Path 3 “Sanchez” Avalanche Path is approximately 72 kPa (1,504 lb/ft²; Figure 3). These pressures fall within the parameters for the Red Zone. The maximum calculated velocity for the design avalanche from Path 3 at St. Lewis Road is 17 meters per second (m/s; 38 miles per hour [mph]; Figure 4).

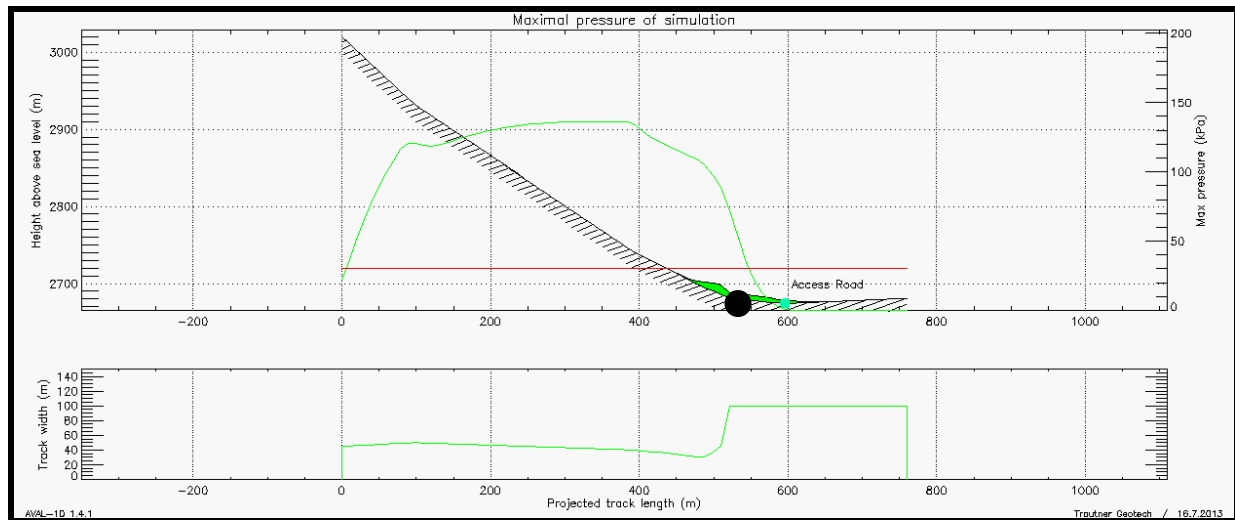


Figure 3. Topographic profile of the Path 3 avalanche path with modeled maximum impact pressure (shown in green) for a release with a 1.5 meter slab. The estimated impact pressure at the St. Lewis Road (black dot) is approximately 72 kPa (1,504 lb/ft²). The red line indicates an impact pressure of 30 kPa on the right Y-axis.

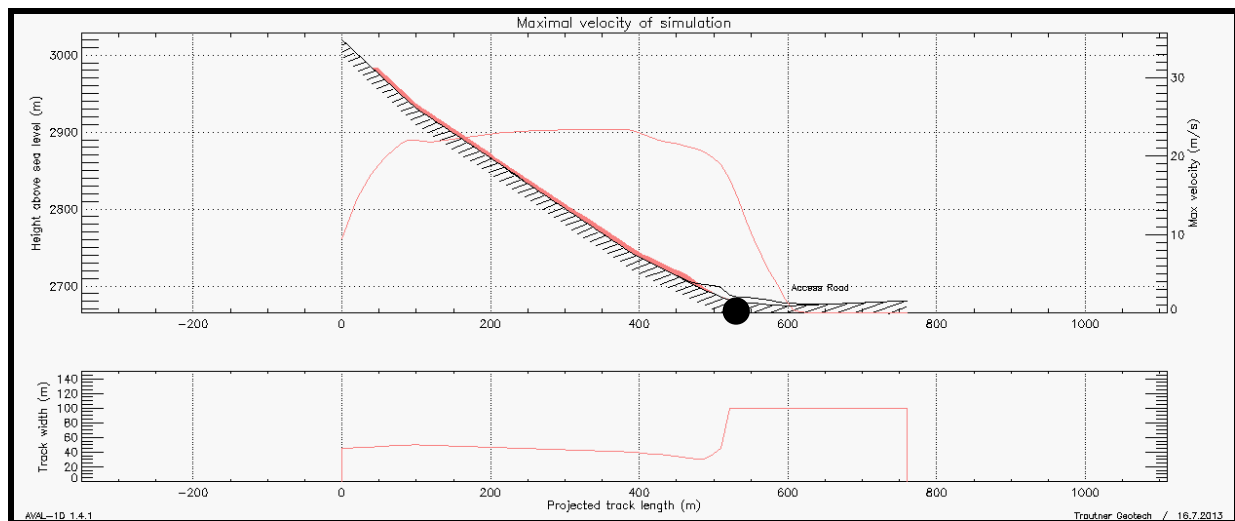


Figure 4. Topographic profile of the Path 3 avalanche path with modeled maximum velocity (in red) for a release with a 1.5 meter slab. Velocity is 17 m/s (38 mph) at the St. Lewis Road (black dot).

The modeled potential flow heights for Path 3 (Figure 5) indicated a maximum estimated flow height of approximately 0.83 meters (2.7 feet) at the St. Lewis Road. This depth represents the flowing height of avalanche debris. Actual snow depths could be much greater if debris hit an object and piled up.

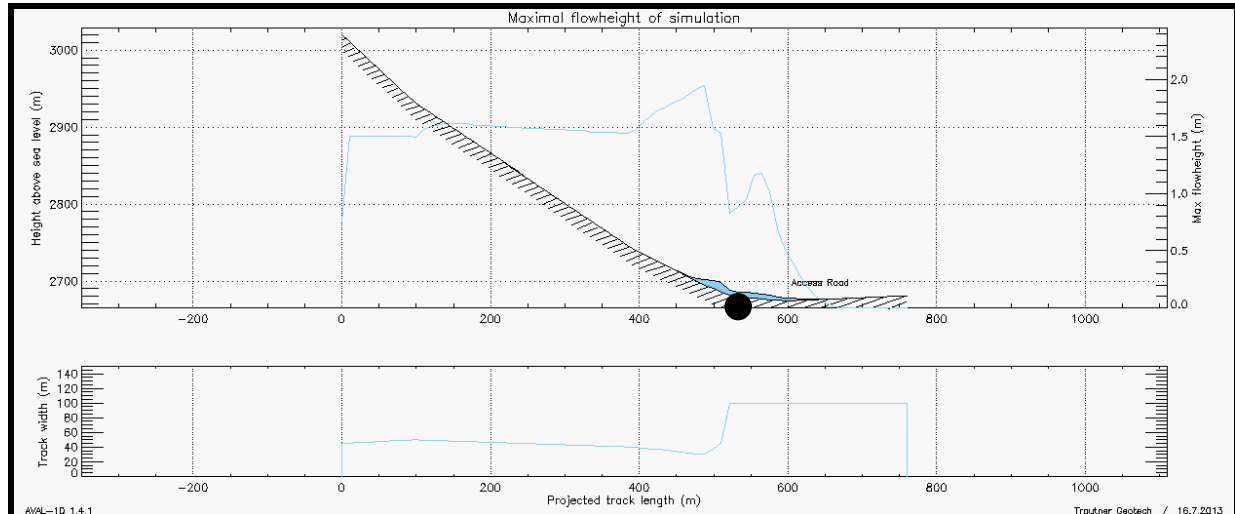


Figure 5. Topographic profile of the Path 3 avalanche path with maximum flow height of snow (in blue) for a release with a 1.5 meter slab. Estimated snow height at the St. Lewis Road (black dot) is 0.83 m (2.7 feet).

4.5 Path 1 Modeling Results

The same calculations performed for Path 3 were performed for Path 1. Figures 6, 7, and 8 show potential impact pressures, velocities, and snow heights of the Path 1 design avalanche.

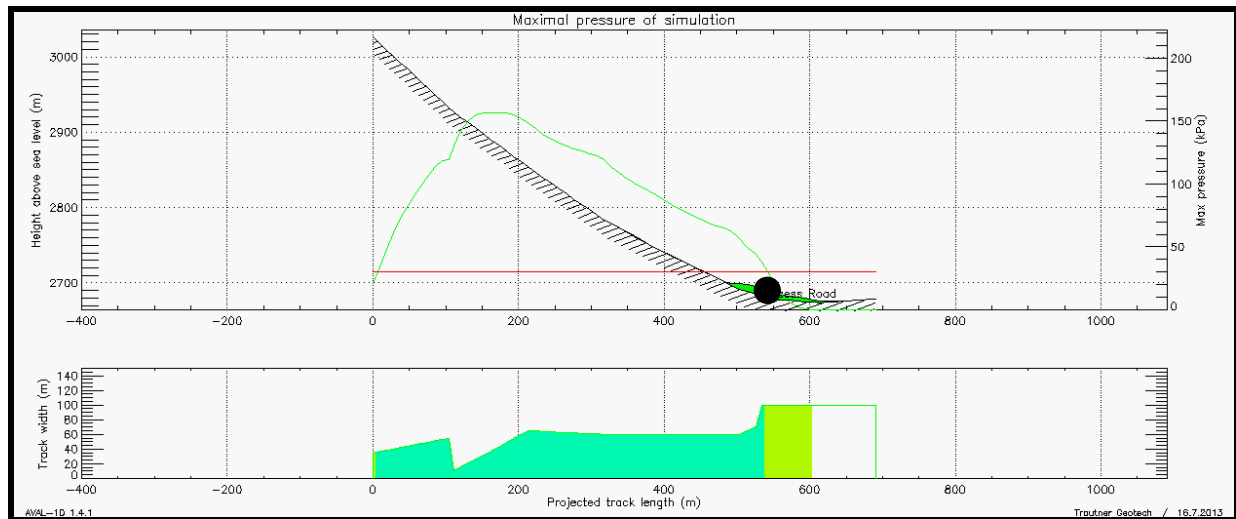


Figure 6. Topographic profile of the Path 1 avalanche path with modeled maximum impact pressure (in green) for a release with a 1.25 meter slab. The estimated impact pressure at the St. Lewis Road (black dot) is approximately 38 kPa (794 lb/ft²). The red line indicates an impact pressure of 30 kPa on the right Y-axis.

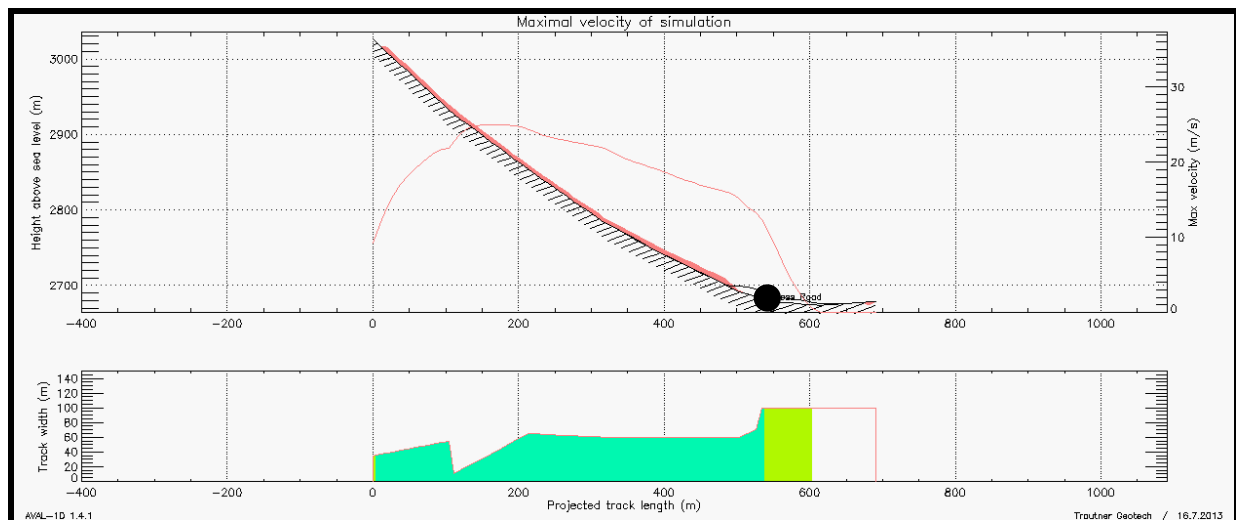


Figure 7. Topographic profile of the Path 1 avalanche path with modeled maximum velocity (in red) for a release with a 1.25 meter slab. Velocity is 12 m/s (28 mph) at the St. Lewis Road (black dot).

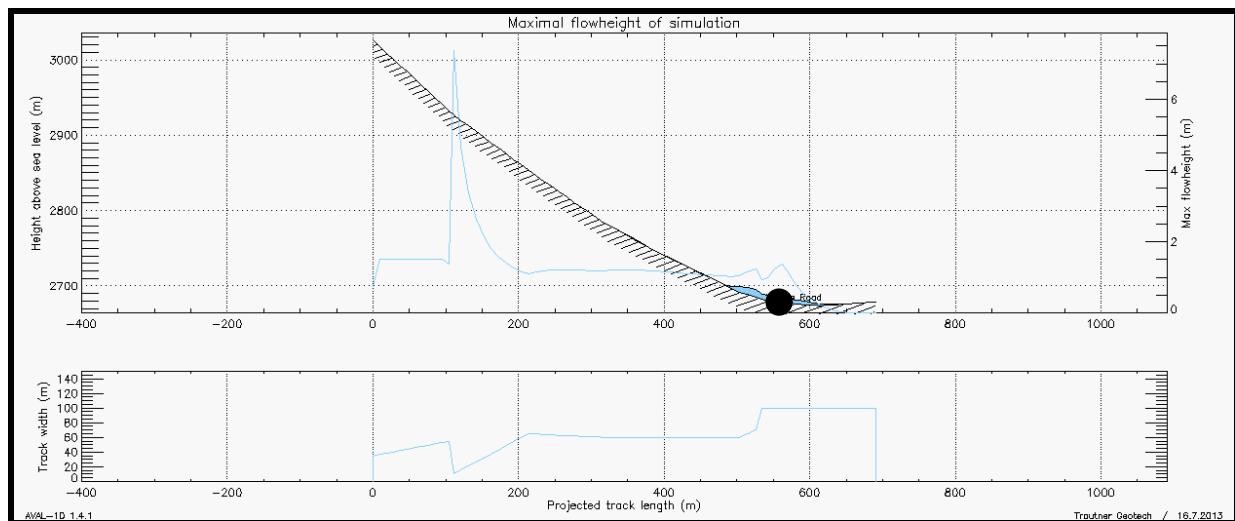


Figure 8. Topographic profile of the Path 1 avalanche path with modeled maximum flow height of snow (in blue) for a release with a 1.25 meter slab. Estimated snow height at the St. Lewis Road (black dot) is 0.94 m (3 feet).

4.6 Potential Avalanche Impact Pressures and Debris Height at St. Lewis Road

The calculated potential impact pressures¹ from design avalanches with 1.5 meter thick slabs from the avalanche paths above the St Louis Ponds area ranges from approximately 38 kPa (794 lb/ft²) to 72 kPa (1,504 lb/ft²) at St. Lewis Road (Figures 3 and 6). These pressures fall within the parameters for the Red Zone. The estimated potential maximum flow height² of snow from avalanche debris at St. Lewis Road is approximately three (3) feet.

4.7 Dendrochronology and Vegetative Indicators of Avalanche Frequency

Trees within and adjacent to the avalanche paths above the St. Louis Ponds area and County Road N were bored with an increment core sampler to determine the ages of the trees. Past avalanche activity also can be interpreted from increment cores and cross sections where the tree has been partially damaged from avalanches. Dendro-chronological techniques can provide a means for reliably dating avalanches and calculating frequencies where sufficient woody vegetation exists for sampling (Jenkins and Hebertson, 2004). Trees and other vegetation were also observed for evidence of flagging or breakage of the uphill branches from avalanche activity.

Ten trees were sampled in or adjacent to the avalanche paths near the site (Figure 9). The approximate age of each tree is shown in Table 1. Trees of similar diameters were noted in areas where samples were taken.

¹ These impact pressures are considered to be conservative and are the maximum expected values for a design avalanche event given the input parameters used in this analysis.

² The flow height does not represent the maximum deposition height that snow can accumulate on the uphill side of a structure as flowing debris decelerates and piles up.

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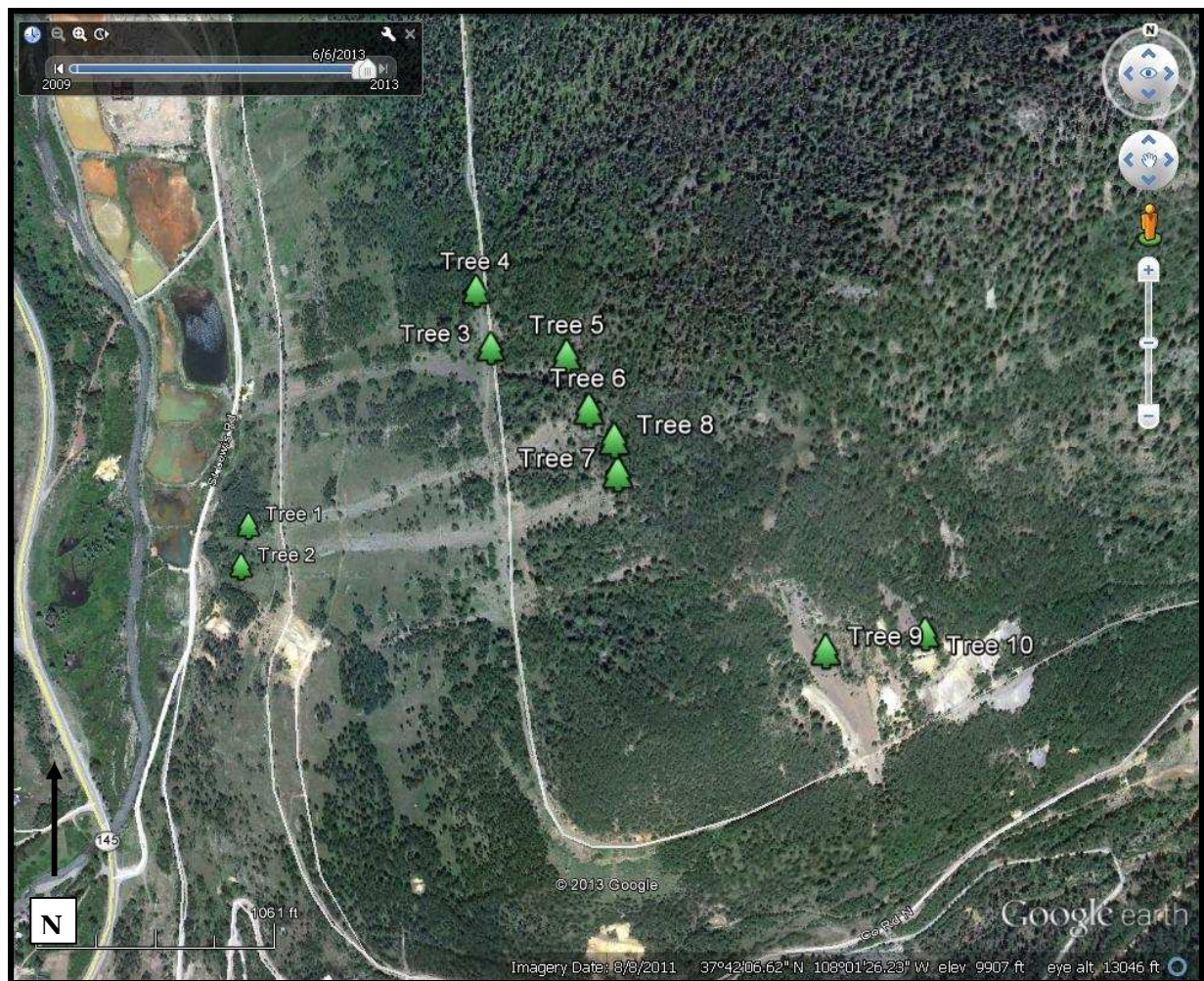


Figure 9. Locations of dated trees near the Rico-Argetine Mine. Numbers correspond to Table 1.

Table 1. Ages of trees in avalanche paths near Rico-Argetine Mine, dated with increment bore.

Location	Type of Tree	Approximate Age (years)
1	Aspen	60
2	Aspen	53
3	Douglas Fir	67
4	Aspen	45
5	Douglas Fir	27
6	Douglas Fir	62
7	Douglas Fir	40
8	Douglas Fir	152
9	Douglas Fir	20
10	Aspen	48

Based on the dendro-chronological techniques and modeling methods described above, the avalanche paths above the St. Louis Ponds area have an approximate return period of 25 years or less. The large avalanche paths along County Road N have an approximate return period of 50 to 75 years.

4.4 Avalanche Hazard to Structures and Access at the Rico-Argentine Mine

We consider that the area along the St Louis Ponds access road is in the Red or High Avalanche Hazard Zone. We consider the area along the access road to the Argentine Mill and the area surrounding the Argentine Mill to be within the Blue or Moderate Hazard zone. The locations of avalanche paths shown on Plates 1 and 2 are based on the history of the paths, size and damage to the trees above the site and the avalanche dynamics modeling we conducted. The estimated impact pressures are based on design avalanches which occur during extraordinary snowfall events and would produce avalanches capable of causing damage to any structure not protected by avalanche mitigation. These events would involve a large storm event coupled with a weak layer of snow on which the storm snow would fall. Normal snowfall amounts can produce avalanches on the subject property and caution should be taken when traveling on or near the slopes during snowfall events. We recommend monitoring of the snow conditions during winter months in the area near the St. Louis Ponds and the Argentine Mill access road to determine if personnel should be cautioned regarding the potential avalanche hazard.

The area along the Mill road for access to the Argentine Mill is considered to be in the Blue or Moderate Avalanche Hazard Zone based on the same criteria as above. The avalanche paths can be considered to have a relatively low probability of occurrence with a low to moderate hazard. The avalanche paths Mill Road 1 through Mill Road 5 do not show any indication that they have reached the access road to the Argentine Mill within approximately the last 50 years. While we consider the avalanche hazard to be relatively low along the access road, a design avalanche event could deposit significant amounts of snow on the access road and pose a potential danger to anyone travelling the road during a heavy storm period.

Mill Road Paths 5 and 6 are located east of the Argentine Mill, but could affect nearby operations and access to nearby portals. Mill Road 6 had two avalanche events that were recorded during the winter of 2012-2013. One of these events deposited avalanche debris into Silver Creek to a depth of approximately two (2) feet.

4.5 Avalanche Mitigation

The estimated impact pressures and snow height amounts that were calculated for the avalanche areas in the vicinity of the St Louis Ponds are within magnitudes that can be mitigated if desired. There are many types of mitigation that would be reasonable at the subject site. A site specific mitigation design is beyond the scope of this report. If site specific mitigation is desired please contact us.

5.0 CONCLUSION

The information presented in this report is based on our surface observations, a review of available literature, interviews with personnel familiar with the avalanche paths, avalanche mapping for the area, dendrochronology, and avalanche dynamics modeling and on our experience in the area. We recommend that we be contacted and included in future design phases and development of this project to provide engineering geology and avalanche hazard mitigation consultation. Please contact us immediately if you have any questions, or if any of the information presented above is not appropriate for the proposed site development.

Trautner Geotech does not provide general civil engineering, or structural engineering consultation. The information in this report should be shown to a competent structural engineer familiar with avalanches so that they may incorporate the estimated impact pressures into any future structure design planned for the property.

The information presented in this letter is applicable only for the St. Louis Ponds area and the Argentine Mill access road and surrounding areas and is based on our surface observations, avalanche history, dendro-chronological tree ring analysis, avalanche dynamics modeling and on our experience in the area. We recommend that we be contacted and included in future design phases and development of this project to provide engineering geology and avalanche hazard mitigation consultation. Please contact us immediately if you have any questions, or if any of the information presented above is not appropriate for the proposed site development.

The avalanche hazard observations presented above are not suitable for adjacent project sites, or for a proposed scope of development which is different than that outlined for this study.

Avalanche hazard can vary depending on a number of factors including but not limited to; snow pack height, snow layer type, wind speed and direction, and meteorological factors before, during and after a storm cycle. We provide an estimate of the potential hazards of a design avalanche for the subject avalanche path, but extraordinary snow or weather phenomena can produce unexpected avalanches in areas that have no evidence of previous avalanche activity.

We are available to review and tailor our study, if needed, as the project progresses and additional information which may influence our evaluation of the site becomes available. Design and feasibility level geotechnical engineering studies of the site will help develop subsurface soil and water information that may be pertinent to roadway and foundation design. Please contact us to establish a scope of service for design phase geotechnical engineering consultation studies and construction phase materials testing services.

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Please contact us if you have any questions, or if we may be of additional service.

Respectfully submitted,
TRAUTNER GEOTECH

Reviewed by

J. Andrew Gleason
Engineering Geologist/Avalanche Specialist

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Principal Geotechnical Engineer

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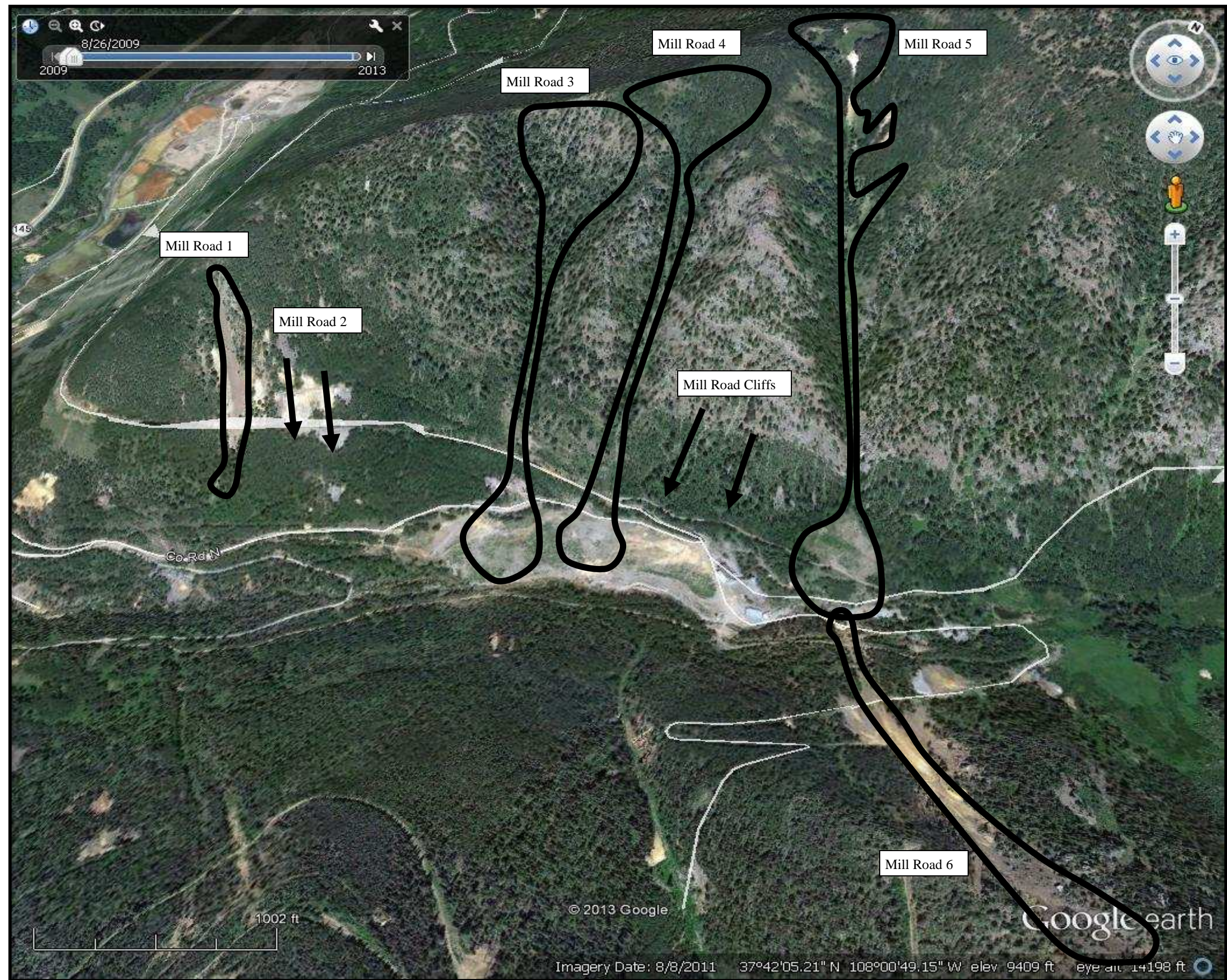


Plate 2. Avalanche Path Map, Argentine Mill and access road.